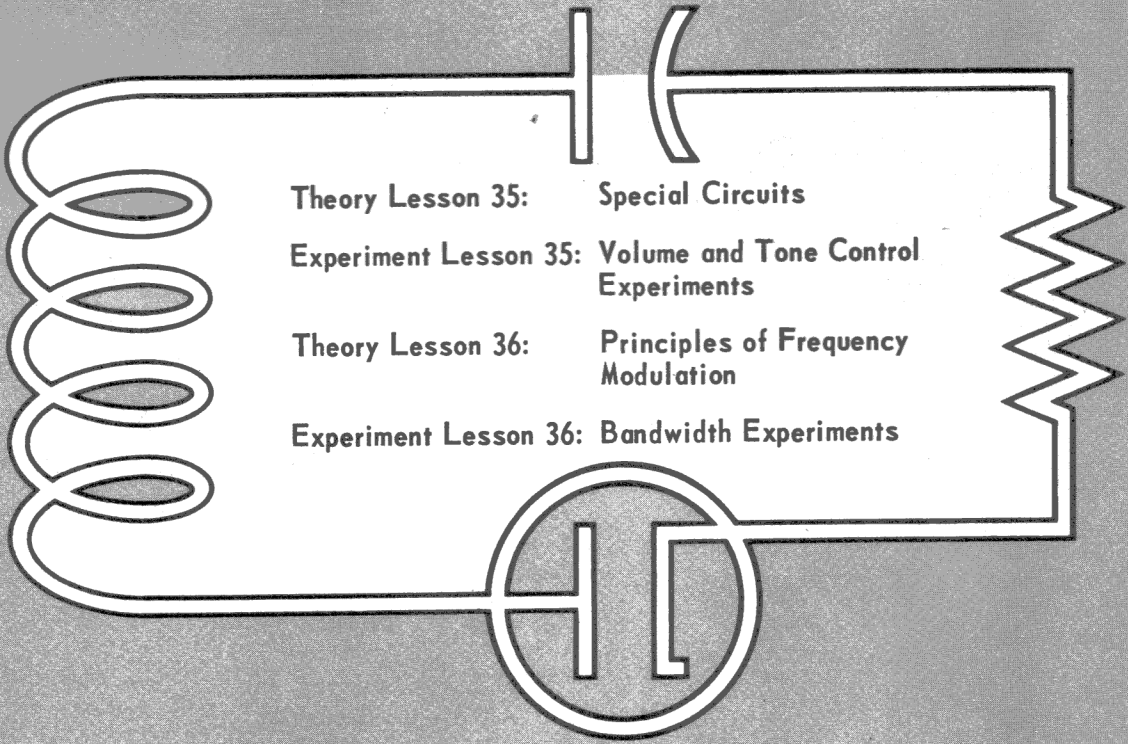


ELECTRONIC FUNDAMENTALS



Theory Lesson 35: Special Circuits
Experiment Lesson 35: Volume and Tone Control Experiments
Theory Lesson 36: Principles of Frequency Modulation
Experiment Lesson 36: Bandwidth Experiments

RCA INSTITUTES, INC.

A SERVICE OF RADIO CORPORATION OF AMERICA
New York, N. Y.



ELECTRONIC FUNDAMENTALS

THEORY LESSON 35

SPECIAL CIRCUITS

- 35-1. Squelch Circuits**
- 35-2. Reflex Stage**
- 35-3. Search Tuners for Auto Radios**
- 35-4. Single Sideband Communication**
- 35-5. Interdepartmental Communication Systems**
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Theory Lesson 35

INTRODUCTION

This lesson discusses a variety of special circuits and techniques. The background of fundamental principles and practices that you have built up by your study of previous lessons is sufficient to enable you to understand these interesting circuits. As you study this lesson, you will see many examples of the ingenuity of electronic design and invention.

At first you may be surprised to discover that certain topics covered in this lesson are related to your interest in radio and television servicing. But as you progress, you'll discover that the knowledge you gain from this lesson will broaden your scope as a serviceman and put you ahead of the average man in your field. And you will be pleased to discover that the special circuits that you study utilize components and circuits with which you are already familiar, that they can be measured and serviced with the instruments you now possess, and that they represent a source of profit to you.

Single sideband techniques, discussed in this lesson, is a subject that is coming into great prominence. The serviceman who understands them and can explain them to others will enjoy a special prestige, for they are a mystery to many servicemen.

35-1. SQUELCH CIRCUITS

In receivers with very high gain, such as certain communications receivers, AVC voltage falls nearly to zero when the receiver is tuned between stations and no carrier is coming in. The only AVC voltage developed is due to rectified noise pulses. But the noise that accompanies this small AVC is amplified by the high gain of the receiver. In receivers such as those used in

police cars to monitor the precinct's transmitter continuously, the noise would be a very disturbing blast every few seconds as the transmitter went on and off the air. (Police transmitters are on the air only when actual speech is transmitted.) In other high gain receivers, the loud noise would be heard whenever the receiver was turned on but not tuned to a station.

A *squelch* circuit is used to eliminate these noise blasts. The circuit is so arranged that the *absence* of AVC, or the falling of AVC below a permissible level, drives an audio tube — usually the first voltage amplifier — to cutoff. With the audio amplifier cut off, no noise is heard, even though the detector stage is applying the noise signal to the audio amplifier's input.

Figure 35-1 is a schematic diagram of a squelch circuit. Note the unusual connection of R_4 , the grid resistor of V_2 . The bottom of the grid resistor is connected to the top of R_3 , the plate-load resistor of V_1 . The lower end of R_6 , the cathode-bias resistor of V_2 , connects to the lower end of the plate-load resistor of V_1 . Although this makes the grid of V_2 very positive with respect to ground, it does not make it positive with respect to the cathode of V_2 , since the cathode is at a greater positive potential with respect to ground. If no voltage drop occurs across plate-load resistor R_3 , point X and point Y will be at the same potential, and the grid of V_2 will have its normal bias, due solely to the small voltage drop across R_6 . But if a voltage drop does occur across R_3 , so that point Y becomes negative with respect to point X, the grid of V_2 will become more negative with respect to the cathode of V_2 . If the voltage drop is large enough, the grid will become so negative that the plate current of V_2 will be cut off. At this time, if a noise signal from the de-

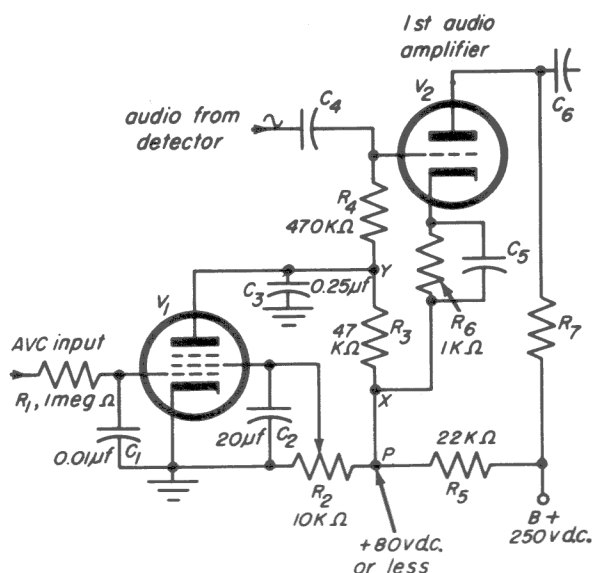


Fig. 35-1

detector is applied to the grid of V_2 , it will not appear at the plate of V_2 and will not be reproduced in the loudspeaker.

Now consider V_1 , a sharp cutoff pentode. Its grid is connected through filter network R_1C_1 , providing additional AVC filtering. When a carrier is coming in, AVC voltage biases V_1 to cutoff. No plate current flows through R_3 . No voltage drop occurs across R_3 . V_2 has its normal bias. Any audio signal from the detector will be amplified by V_2 , passed on to the power output tube, and reproduced by the loudspeaker. But when no carrier is coming in, AVC voltage will be small and will not bias V_1 to cutoff. Plate current will flow through R_3 . The voltage drop due to plate current in R_3 will make point Y so much more negative than point X that the grid of V_2 will be biased to cutoff. The noise voltages present in the detector output when no carrier is coming in will not be amplified by V_2 . They will be squelched.

Potentiometer R_2 allows the screen grid voltage of V_1 to be varied. Adjustment of this screen grid voltage varies the cut-off point of V_1 . When screen grid voltage is low, a very small AVC bias will cause cut-off. When the screen grid voltage is high, a larger AVC voltage is required before cutoff is reached. Thus, R_2 sets the threshold at which V_1 can disable V_2 . It may even be set so that only a very strong carrier will drive

V_1 to cutoff and thereby allow V_2 to operate. At this setting, even interfering carriers, if not as strong as the desired carrier, can not break in and be heard.

35-2. REFLEX STAGE

It is possible to increase the over-all gain of a receiver without increasing the number of tubes by including a stage of reflex amplification in which the signal is amplified twice. As shown in the block diagram of Fig. 35-2, the incoming signal passes through the stage at one frequency, such as the i.f., is then detected, folded back upon its path (or reflexed), and fed into the same stage at audio frequency. In order to avoid oscillation, the signal must undergo a change of frequency before its second passage through the reflex stage.

A reflex stage is shown schematically in Fig. 35-3. It is an i-f amplifier and an audio voltage amplifier in one. The signal from i-f transformer, T_1 , is applied to the control grid of V_{2A} . The amplified i.f. from V_{2A} goes via i-f transformer T_2 to the diode detector V_{2B} . (V_{2B} is shown separately here; actually it is in the same envelope with V_{2A}). The diode detector rectifies the i-f signal. The rectified a-f signal then passes back via volume control R_8 , coupling capacitor C_{11} , filter resistor R_2 , and the secondary of T_1 , to the control grid of V_{2A} . This a-f signal is amplified by V_{2A} . It appears as an a-f variation in the plate current of V_{2A} . This varying plate current cannot develop an audio frequency voltage across the primary of T_2 , which has approximately zero impedance for audio frequencies. But the varying plate current can develop an a-f voltage across R_6 , the audio load resistor in series with the primary. The voltage drop

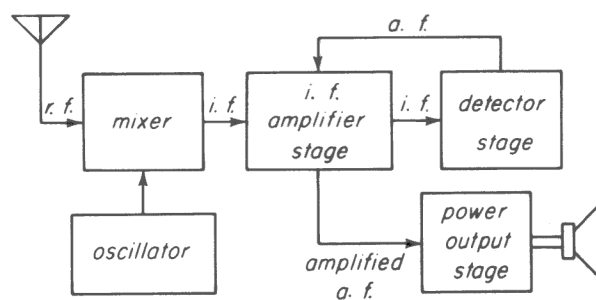


Fig. 35-2

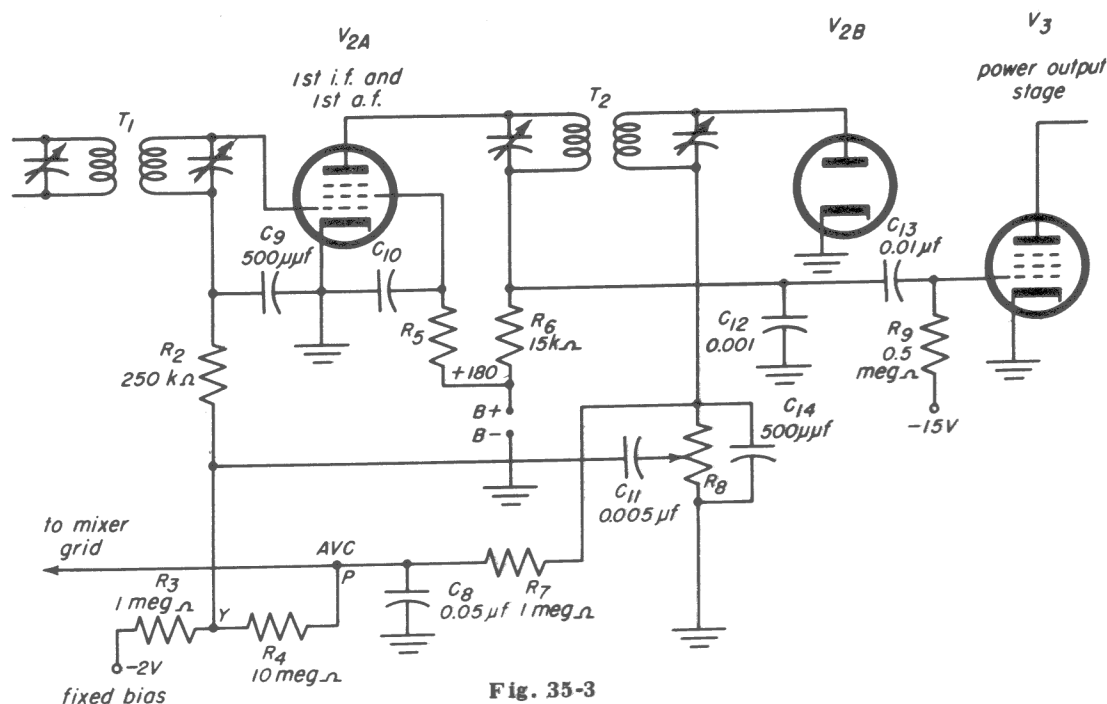


Fig. 35-3

across R_6 is applied, via C_{13} , to the control grid of the power-output tube.

Now that we have discussed the operation of the circuit, let's consider some of the interesting details of its operation.

The filtering of the rectified (detected) i-f signal is very thorough. Note the high value of bypass capacitors, C_{14} and C_9 . These prevent any appreciable remnant of the i-f voltage from being reflexed along with the a-f voltage. They also slightly attenuate signals in the upper a-f range. Capacitor C_{12} holds the low end of the primary of T_2 at ground potential for i-f. The bypassing keeps the residual i-f. from the detection process from being strong enough to initiate oscillation in V_{2A} , and it also keeps residual i-f. out of the power output stage.

Because the plate load resistor, R_6 has a relatively low value, the high audio frequencies developed across it are not heavily attenuated by C_{12} .

Capacitor C_{12} is in effect shunted across R_6 . The low end of R_6 is held at ground potential, for signals of all frequencies, by the power-supply filter capacitor. But the impedance at upper audio frequencies of C_{12} in parallel with R_6 , is only slightly

less than the resistance of R_6 alone. At intermediate frequencies, however, the impedance of C_{12} and R_6 in parallel is very low, so that negligible signal voltage at the i-f. can develop across the combination.

Note that at point P the total AVC voltage is applied to the mixer circuit. A portion of the AVC voltage is obtained from R_3R_4 voltage divider and is applied to V_{2A} . The values of the resistors in this voltage divider are so chosen that only one-eleventh of the total available AVC voltage is applied to the grid of V_{2A} . If the total AVC voltage were applied to the grid of V_{2A} , strong stations, which develop very large AVC voltages, might bias V_{2A} too much. As a result, V_{2A} would operate on a very non-linear part of its e_c-i_b curve. Under such conditions, V_{2A} would detect the i-f. (just like a plate detector). The detected i-f. would be applied across the audio load resistor, R_6 and go directly to the power output stage. Thus, the spurious audio would not go through the diode detector and the volume control. Then, even with the volume control at zero, some audio could be heard from the speaker. The audio volume could not be turned all the way down if desired. But this does not happen because the range of AVC voltage is limited and fixed bias is used in series with the limited AVC voltage.

The tube is kept operating on a reasonably linear part of its curve for all signal strengths. It also is properly biased for audio amplification.

35-3. SEARCH TUNERS FOR AUTO RADIOS

In recent years, the search tuner, a type of automatic tuner for automobile radios, has gained widespread popularity with car owners. It enables a driver to tune in a station on his radio without taking his eyes off the road, and without having his hand off the steering wheel for more than a few seconds. What is even more important, the driver does not have to *think* about the tuning operation — he keeps his mind on the problems of driving, while the set, once started, tunes itself in.

There are several variations of the tuner, but the differences are minor. The basic principle is the same in all search tuners. A motor turns the tuning shaft, causing the indicator to move across the dial until a station comes in. Then the amplified

signal voltage actuates a tube-and-relay circuit, which disengages the tuning shaft from the motor and shuts off power to the motor, leaving the tuner stopped on the station. Thus, even though the car operator may be driving through unfamiliar territory, knowing nothing about the carrier frequencies of stations in that region, the set will automatically keep searching until it finds one with a signal strong enough to trigger the tuner-stopping circuit.

Radio receivers that use search tuners are equipped with sensitivity controls. A sensitivity control can be adjusted so that the tuner will stop only on strong signals, only on strong and medium strength signals, or on the first station — weak, medium, or strong — that the tuner comes to (unless the signal is so weak that even at maximum receiver gain it cannot trigger the tuner-stopping circuit).

A schematic diagram of a receiver that uses a search tuner is shown in Fig. 35-4. In the lower right-hand corner of the diagram are S_1 which starts the motor of the tuner,

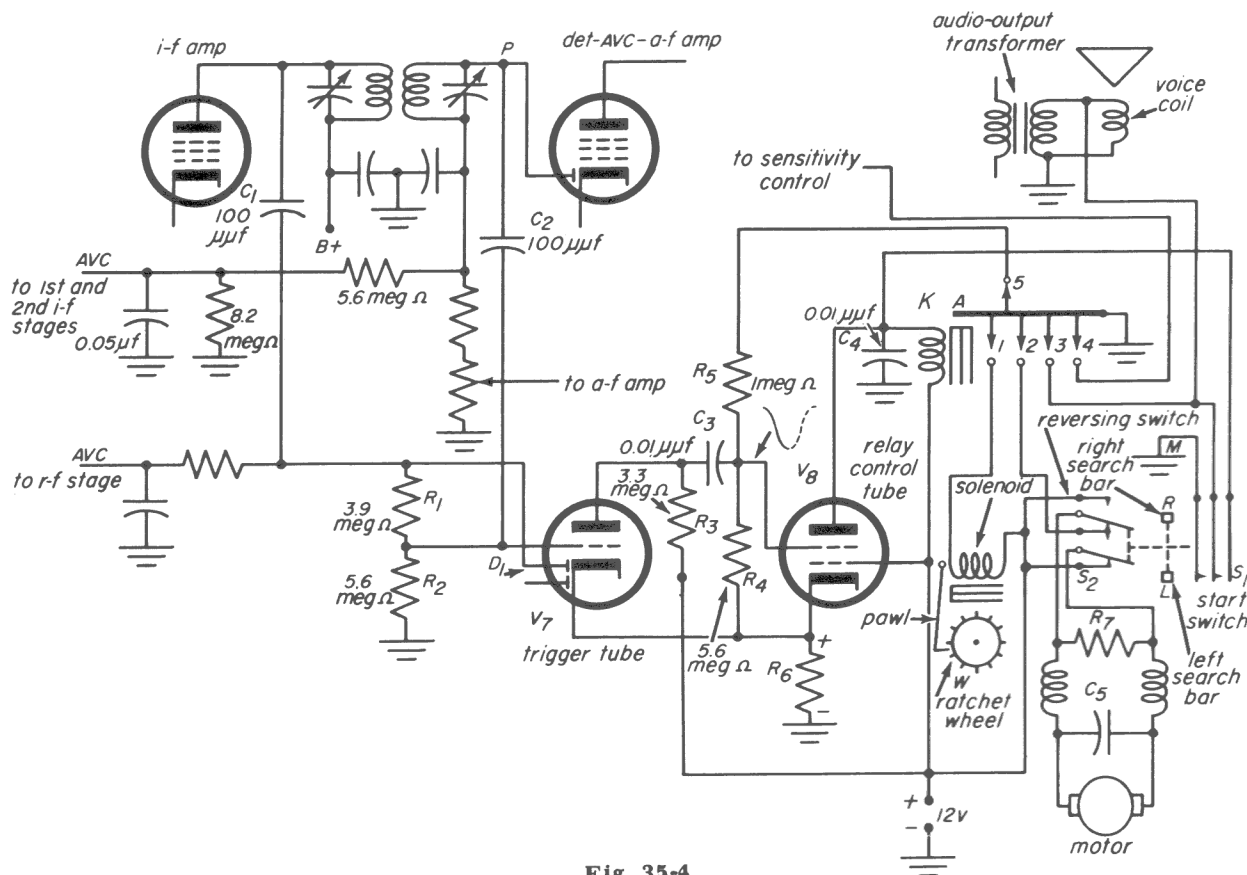


Fig. 35-4

and S_2 , which determines the direction in which the motor will rotate. S_1 and S_2 are ganged. When a motorist wishes to start the search tuner, he presses one of the two search bars that project through the front panel of the set. Pressing either of the search bars will turn on the motor; but the direction in which the motor turns depends upon which of the search bars is pressed, because one search bar supplies current from 12 volts flowing through the motor windings in one direction and the other search bar applies it so it flows through them in the opposite direction.

As the motor rotates, the ganged powdered-iron cores that control the tuning, are moved in or out of the coils. A moving frame to which the cores are mounted, simultaneously moves the tuning indicator across the dial. When the frame has carried the dial indicator all the way across the dial, a catch on the moving frame throws reversing switch S_2 . As a result, current flow in the motor windings is reversed. The moving frame reverses direction, and the dial indicator moves back in the direction opposite to the one in which it has been traveling. When the moving frame reaches the end of its travel in this direction, a catch trips S_2 and the direction of travel is reversed again. The search tuner keeps sweeping the broadcast band until a station comes in or the set is turned off.

Let's discuss the electrical operation of this circuit in more detail. We'll begin with the start switch, S_1 . The purpose of this switch is to activate the relay, K , which is shown in the schematic in the inactivated position. When either of the search bars ganged to switch S_1 is pressed, all three contacts of the switch are momentarily connected together. Current flows from ground (-12 volts) through the switch, through the high-resistance winding of the relay K to +12 volts. The current flowing through the winding of the relay causes the relay to operate, thus pulling the armature of the relay down. When the armature is pulled down, it no longer makes contact with contact 5. Instead, it makes contact with contacts 1, 2, 3, and 4.

Now the start switch has done its work. The motorist has removed his finger from the pushbutton. But the armature of the relay does not return to the inactivated position. As soon as the armature was away from contact 5, a small negative bias was removed from the control grid of tube V_8 . As a result, the plate current of V_8 is increased. This increased plate current, passing through the winding of the relay, is sufficient to hold the armature down even though the motorist has removed his finger from the search bar and S_1 is now open.

When the armature is held against contacts 1, 2, 3, and 4, four new circuits are activated. Let's follow what happens contact by contact, starting, for the sake of simplicity with contact 2.

Closing contact 2 supplies current to the motor windings. The current flows from ground through the armature bar and contact 2 to switch S_2 . Depending upon the position of S_2 , the current will go either one way or the other through the motor windings on the way to +12 volts. When current goes through the motor windings, the motor rotates.

Closing contact 1 mechanically couples the motor shaft to the tuning slugs. Current flows through contact 1 to the high-resistance winding of the solenoid (a solenoid is an electromagnet) and from there to +12 volts. When the solenoid is energized, it pulls the pawl against the ratchet wheel. This ratchet wheel is a clutch. When the pawl is pressed against the clutch, idler gears on the clutch become active and transmit rotation of the motor to the shaft of the tuning mechanism.

Closing contact 3 shorts out the voice coil of the speaker. As a result, during the time that the tuning unit is searching, no motor noise and no interchannel (between stations) noise will be heard. This is necessary because there is no AVC while the radio receiver is not tuned to a station and the gain of the radio between stations is at maximum permitted by the setting of the sensitivity control.

Closing contact 4 connects the sensitivity control into the circuit. The effect of the

sensitivity circuit, which we will consider later in more detail, is to make the tuner more or less sensitive to signals of a given strength. The relay remains activated and the armature remains against contacts 1, 2, 3, and 4 until the tuner finally tunes in on a station. Then the i-f signal that results when the receiver is tuned in sets off a chain of events that deactivates the relay, thereby shutting off the search tuner and permitting the set to stay tuned in to the station to which the search tuner has tuned it. The i-f signal is applied to the control grid of trigger tube V_7 , which, when no signal is applied to the grid, is cut off.

V_7 is normally cut off because its cathode is kept positive with respect to its control grid. The cathode is positive because the plate current from V_8 flows through R_6 which is the cathode resistor for both V_7 and V_8 . However, when the i.f. appears suddenly (due to the speed of motor tuning) and is applied to the control grid of V_7 , the positive half cycles of i.f. are able to make the grid more positive than the cathode. As a result, V_7 conducts during every positive half-cycle of i.f.

Each time that V_7 conducts, plate current flows through the plate load resistor R_3 . The average value of plate current pulses through the plate load is equivalent to a d-c current through the plate load resistor. This produces a voltage drop across R_3 , so that voltage decreases suddenly at the plate of V_7 . This sudden voltage drop, applied to the control grid of V_8 (in this tube, the control grid is closer to the plate than is the screen grid), cuts off V_8 . As a result, the plate current from V_8 , which had been activating the relay and thereby holding the armature against contacts 1, 2, 3, and 4, no longer flows through the relay. The armature goes back up and makes contact with contact 5. Then negative bias is again applied to the control grid of V_8 , thereby keeping V_8 in its already cut-off state. Thus, the armature will remain against contact 5.

With the armature against contact 5, it is disengaged from contacts 1, 2, 3, and 4. Current does not flow to the motor through contact 2, so the motor stops turning. Cur-

rent does not flow to the solenoid by way of contact 1, so the pawl is no longer pressed against the clutch. As a result, the motor is no longer mechanically coupled to the tuning slug.

Since there is no connection through contact 3, the voice coil is no longer shorted out. Because contact 4 is open, the sensitivity control is no longer in the circuit.

Notice that +12 volts source shown on the schematic diagram is the B supply for the tubes. Although the receiver shown is a conventional superheterodyne in most of its circuitry, it uses a complement of tubes specially designed to operate with very low plate and screen grid voltages. This permits B current to be taken directly from a 12-volt storage battery. No vibrator, no voltage step-up transformer, and no rectifier tube are needed. But this arrangement makes it impracticable to use a conventional power output tube. A power output tube supplied with such low plate and screen voltage would not draw enough plate current to give adequate power output, which is harder to obtain, with low voltage, than voltage gain. Therefore, a power output transistor is used to replace the usual power output tube. It provides 2.5 watts of undistorted audio output power. Transistors normally operate at low supply voltages, and can be easily designed to draw heavy currents.

In our discussion of tube V_8 , we mentioned that the positions of control grid and screen grid are reversed in the design of this tube. There is a good reason for this type of design. Having the screen grid nearer the cathode increases the amount of plate current that can flow at low plate voltages. Thereby making operation of the relay more certain when the control grid bias permits conduction. (But this method could not increase current enough for good power output performance.) Next, note that grid resistor R_4 returns to the cathode of the tube, so that when relay contact 5 is open, the grid of the tube is at zero bias with respect to the cathode, and plate current is at maximum. But when contact 5 is closed, R_5 , a grid resistor of much lower value returns, not to cathode, but to ground. Since ground is

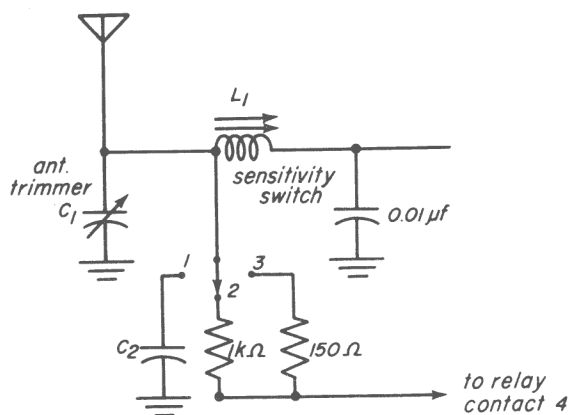


Fig. 35-5

negative with respect to the cathode, due to the voltage drop across the cathode resistor R_6 , the grid is also negative with respect to the cathode because the grid is now connected to a point near the negative end of voltage divider R_4R_5 , shunted across R_6 .

The circuit of the sensitivity control is shown in Fig. 35-5. The control is a three-position switch. With the switch in position 1, antenna coil L_1 is shunted by just the right amount of capacitance to achieve optimum operation. When the switch is in either position 2 or position 3, L_1 is slightly off optimum operation and is loaded by a resistor, which lowers its Q . However, this load is applied only during the time that the search tuner is operating, when relay contact 4 is closed and the low end of the resistors is grounded. The load imposed by the resistors has the effect of making medium or weak stations too weak to trigger the tuner-stopping circuit. Thus the sensitivity switch can be set so that the tuner will stop on strong stations only, when the switch is in position 3; on medium-strength and strong stations when the switch is in position 2; and on weak, medium, and strong stations when the switch is in position 1.

When the driver is not after some specific station, it is preferable to set the sensitivity control so that the receiver will tune in strong stations only. Normal variations in signal strength — due to the automobile's course passing under viaducts, around hills, near steel buildings, etc. — are less likely to go beyond the range for which AVC can compensate, if the set is tuned to a strong station.

When the search tuner is in operation, it is important that a noise pulse does not stop the tuning action. It is possible for the search tuner to discriminate between short noise pulses and the much longer triggering pulse from a radio station because of the effect of capacitor C_4 . Let's follow a noise pulse through the circuit, starting at V_7 . A positive noise pulse drives the grid of V_7 positive. Therefore, V_7 conducts. The voltage drop across R_3 , the plate load resistor of V_7 causes the voltage at the plate of V_7 and therefore, the voltage at the grid of V_8 to fall. When the voltage at the grid of V_8 falls, V_8 is cut off. Were it not for the action of C_4 , this would mean that current would stop flowing through the winding of the relay, thereby permitting the relay to go back to its off position, with the armature against contact 5.

But, before the noise pulse arrived, and during the time that V_8 was conducting, C_4 was charged to a certain level, lower than $B+$. C_4 could not charge up to the level of $B+$ because of the voltage drop across the high resistance coil of the relay. However, when a brief noise pulse cuts off V_8 , plate current no longer flows through the high resistance of the relay winding. But since the charge across C_4 is less than 12 volts, charging current now flows through the coil, gradually bringing C_4 's charge up to the level of $B+$. The effect of C_4 charging up to the level of $B+$ is that more electrons leave the plate side of the capacitor and move through the coil of the relay, thereby producing a current strong enough to activate the relay and hold in the armature against contacts 1, 2, 3, and 4.

After a certain amount of time, determined by the time constant of C_4 and the resistance of relay winding, the charge on the capacitor reaches the $B+$ level. But by that time, the momentary noise pulse is over and is no longer causing V_8 to be cut off.

During the much longer interval taken up by the triggering pulse generated by the i.f., the charge on C_4 reaches the $B+$ level, C_4 draws no more current, the triggering pulse keeps V_8 cutoff, no plate current flows in the winding, and the relay opens, stopping

the search operation while the tuner is on the station.

Trigger tube V_7 contains a diode, D_1 , coupled through capacitor C_1 to the plate of the last i-f amplifier tube. Signal voltage from the plate, applied to D_1 is rectified and develops a negative voltage between D_1 and ground. The voltage is proportional to the strength of the incoming signal. An appropriate portion of this voltage is taken off voltage divider R_1R_2 and applied to the control grid of V_7 . This adjusts the triggering sensitivity of V_7 to the strength of the incoming signal: a stronger signal has to overcome a larger negative bias on the control grid in order to cause a given amount of plate current to flow. Without proportional bias from D_1 , strong signals would trigger V_7 before they were fully tuned in, causing the tuner to stop at the edge of the station's channel, instead of in the center.

35-4. SINGLE SIDEBAND COMMUNICATION

It is possible to transmit audio information, particularly speech, by radiating only *one* set of sidebands. The carrier and the other set of sidebands — usually the lower sidebands — can be suppressed completely.

In an earlier lesson, you learned that an AM signal consists of a carrier and sidebands. There is a pair of sidebands for each single audio frequency. The frequency of each sideband of a pair of sidebands differs from the carrier frequency by an amount equal to the frequency, or pitch, of the audio signal that the sideband represents. If the sidebands were lost on the way to the receiver, so that only the constant-amplitude carrier arrived, no audio would result. The sidebands which vary in frequency are necessary. The sidebands beat against the stable carrier to produce the difference frequencies. The difference frequencies are the audio waveform.

If the carrier were lost, so that only the sidebands reached the detector, the audio waveform still would not be produced. Only the combined signal can have the audio waveform. However, if only one set of sidebands were lost, so

that the other set of sidebands and the carrier arrived at the detector, the audio waveform would be produced. One set of sidebands would beat with one fixed frequency signal, the carrier, to produce the audio frequencies. The audio signal resulting would be only half as loud as when both sidebands were received, but the volume control of the receiver could be advanced to compensate. It would not then be possible to tell by listening that one set of sidebands was missing. (From here on, one set of sidebands will be called simply one, or a single, sideband.)

The receiver needs at least one sideband and a carrier to produce an audio output. When the carrier emerges from the converter stage, of a receiver, it is a carrier at the intermediate frequency; the sideband is an i-f sideband. The i-f carrier is a fixed-frequency signal, let's say 455 kc. The i-f sideband will beat with *any* fixed-frequency signal of 455 kc to produce the audio waveform. Thus, the i-f carrier with which the i-f sideband beats need not be derived from the carrier sent out by the broadcast station. *Any* i.f. of 455 kc will be satisfactory. For instance, the i-f carrier can be generated in the receiver by the BFO. Thus, it is possible for the station to suppress (omit) the r-f carrier and transmit only a single sideband. The incoming r-f sideband, converted to an i-f sideband, will beat with the 455-kc generated in the BFO and produce the desired audio waveform.

Single-sideband transmission offers tremendous advantages. All the power ordinarily used to radiate the carrier and two sidebands can be put into one sideband. That is, all the power can be put into the information-containing part of the signal. No power is wasted on the carrier or on the extra sideband. A well-engineered SSB transmitter can have a greater effective range.

Since only one sideband has to be passed, the bandpass of the receiver can be made half as wide, thereby cutting interference, from undesired signals and noise in half.

Short-wave reception all over the spectrum benefits from SSB transmissions, because SSB stations use channels only half as wide as stations transmitting both sidebands. The narrower the channels are, the more stations are accommodated in the crowded radio spectrum.

Carrier and Sideband Suppression. In order to generate the single sideband to be transmitted, the station must first generate a carrier and modulate the carrier with the audio signal. This produces upper and lower sidebands. The carrier and the unwanted sidebands are suppressed. The remaining sideband is greatly amplified, and then transmitted. Very little power is wasted in generating the carrier, because this is done in a low-level stage of the transmitter; suppression of the carrier takes place before the signal reaches the power-output stage of the transmitter.

Elimination of the carrier is accomplished in the same circuit that generates the sidebands. One such circuit is called a balanced modulator (Fig. 35-6). It is a modulator because it mixes the audio and the carrier signals to generate sidebands. It is balanced because the plate-to-plate output impedance, L_2 , is center-fed from B+ by the center tap, so that the tubes have equal load impedances. The cathode bias is adjusted so that the tubes draw equal plate currents. Except for the fact that the output transformer, T_1 is a tuned r-f transformer, the plate circuit resembles the push-pull output circuit of an audio amplifier.

As you may recall, the signals applied to the control grids of a push-pull stage must be 180 degrees out of phase in order to produce an output signal. If the signals applied to the grids are in phase, their outputs cancel in the center-tapped plate-to-plate load. Note that the control grids are connected together, instead of being connected to opposite ends of a center-grounded input inductor. The r-f carrier signal applied to the control grids is therefore applied in phase. Although such a signal will vary the plate current of both tubes, no output at the carrier frequency will flow in L_3 , due to cancellation, even though L_2 is tuned to the

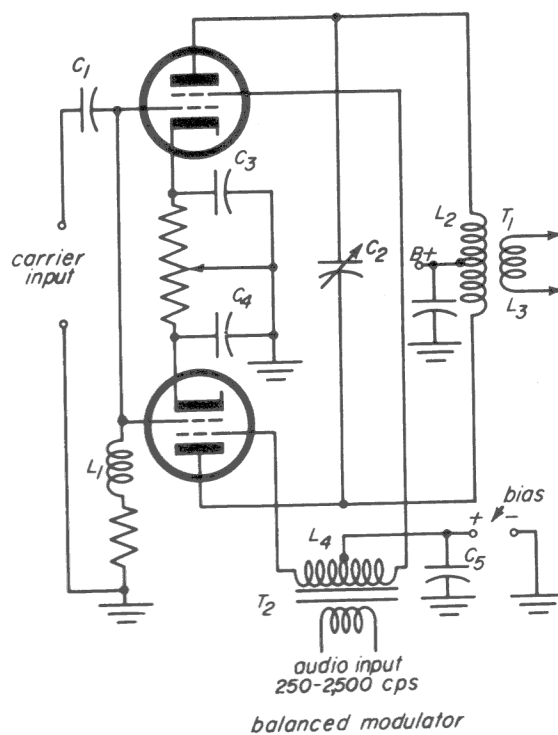


Fig. 35-6

carrier frequency by C_2 . Current flowing in the upper half of L_2 induces a current flowing one way in L_3 , while a current in the lower half of L_2 induces a current flowing the other way in L_3 . Thus, L_3 has equal but opposite currents flowing in it. Equal and opposite currents in the same circuit cancel.

Now note T_2 , the audio input transformer. Its secondary, L_4 , is center-tapped. The tap is held at audio ground potential by audio-bypass capacitor C_5 . The screen grids are connected to opposite (180-degrees out-of-phase) ends of L_4 . The audio signals, superimposed on the screen-grid bias, vary the plate current of each tube. Although the audio signals are applied out of phase, and are out of phase at the plates, they do not produce audio signals across T_1 because the primary, L_2 , is tuned to the carrier frequency, and has almost zero impedance for the audio signals.

Since both audio and r-f signals vary the plate current of each tube, sum and difference signals — sidebands — are generated, in the plate-to-plate load. These sidebands, like the audio that beat against the carrier to generate them, are out of phase at the plates, and therefore do not cancel. L_2 ,

tuned to the carrier frequency, has a band-pass broad enough to respond to the sidebands because they differ in frequency only slightly from the carrier. The sidebands are passed by the transformer and appear in L_3 .

From L_3 the sidebands are passed on to a sharp filter which removes one sideband, usually the lower, leaving the remaining upper sideband to be greatly amplified and then transmitted.

Since SSB signals are used primarily for communication, and since good speech intelligibility can be realized with an audio range of 250 to 2,500 cps, the audio input signal, applied to the screen grids, is restricted to this range. Therefore, no sideband frequency will differ from the suppressed carrier frequency by more than 2.5 kc. The transmitted bandwidth is therefore only 2.5 kc. The receiver can use a narrow bandwidth of only 2.5 kc, and yet accept the signal fully. Compare this to the 15 kc or even 20 kc bandwidth of some receivers used for broadcast listening.

How to Tune in SSB Signals. The simple, familiar method used for tuning in an AM signal is not suitable for tuning in a single sideband signal. With the BFO off, the SSB signal is not heard as intelligible speech, because there is no carrier present for the sideband to beat against. With the BFO on, AVC is constantly high (since it is rectified BFO voltage) and does not adjust the gain of the receiver to widely varying signal strengths as you tune over a short-wave band. With AVC switched off, but BFO on, every AM station you pass over as you tune generates a piercing whistle as its carrier, after conversion to the i.f., beats with the BFO signal.

In order to tune in a single-sideband signal, have AVC on, but BFO off. Watch the S meter instead of listening for an audible signal. When an SSB signal comes in, the S meter will swing back and forth, as the rectified SSB signal varies in strength and therefore varies AVC voltage. (The strength of the SSB signal varies with the loudness of the voice at the transmitter — when the voice is loud, the SSB is strong; when the voice is faint, the SSB is weak.)

Using the range of the S meter swings as a guide, tune the SSB signal for maximum deflection range, and then leave the tuning controls in that position. Switch off the AVC voltage. Turn r-f gain to minimum and audio gain to maximum. Switch on the BFO. Then slowly advance the r-f gain control until a voice, however strange sounding and unnatural, is heard. Then very slowly vary the frequency of the BFO until the pitch of the voice sounds natural. This last operation puts a carrier of accurate frequency into the i-f system, so that the SSB can beat against a carrier as nearly as possible identical to its original carrier, which was suppressed at the transmitter.

The reason that the r-f gain control must be kept low is that this control usually regulates the gain of only one or two stages, whereas the signal may have to pass through four or five stages before reaching the detector. If two or three stages are operating at full gain (due to having AVC off), the last of these stages may receive an input signal strong enough to overload it. In such a situation, the output signal will be distorted. Keeping the over-all r-f gain as low as possible tends to avoid this overloading.

Furthermore, a strong interfering station may be coming in at a frequency close to that of the desired signal. If the interfering signal is rectified (detected) by the diode, its audio output will be heard together with that of the desired signal. (Two distinct voices, of approximately equal loudness, may be confusing — more so than one distinct voice heard against a steady whistle or against unintelligible chatter.) Turning the r-f gain down helps discriminate against the interfering signal. The BFO develops a relatively large and steady negative voltage at the ungrounded end of the diode load resistor. This negative voltage biases the diode, even though the AVC is shorted (isolation of the short by the large AVC filter resistor prevents shorting of the detector load resistor). If the peak amplitude of the interfering signal can be kept much lower than the diode bias (by turning down r-f gain), the peaks of the undesired r-f signal will not be able to overcome the bias, the diode will not conduct for them, and the

undesired audio will not be recovered. But the desired audio will be recovered because the SSB signal, combined with the BFO signal, will in effect, ride on the peaks of the BFO signal, which are large enough to overcome the bias. The audio content of the SSB signal will be recovered.

The interfering signal will not be wholly eliminated by the process just described. The interfering carrier will beat with the BFO, thereby superimposing a difference frequency on the BFO peak. If the pitch of this difference frequency is within the audio range, it will be heard as a steady whistle. The sidebands of the interfering signal will also beat with the BFO causing *monkey chatter*, a frequency varying in pitch, with the rhythm of speech. Monkey chatter is unintelligible, since the interfering sidebands are not truly tuned in and are off their true i-f sideband frequency. Consequently they produce sounds off their true audio frequency.

The r-f gain cannot always be lowered. Often, a desired signal is so weak that high r-f gain is required. In such a circumstance, it is helpful to have a *product detector*, which discriminates against interfering signals without the r-f gain being turned down.

The Product Detector. Before describing the product detector, whose circuit is given in Fig. 35-7, let us quickly review the major characteristics of the diode detector,

so we can contrast them to the major characteristics of the product detector:

The diode detector is an envelope detector. It responds to variations in peak amplitude of the applied signal. Both carrier and the sidebands are applied as a combined signal to the same input, the diode plate.

The product detector (Fig. 35-7) is not an envelope detector. It is a frequency-converting detector. It has two inputs. The sideband is applied to one input and the carrier (BFO signal) is applied to the other. The difference frequency, or audio, appears at the output. Instead of using one diode, it uses three triodes.

Notice that the twin triodes, V_1 and V_2 , (usually contained in the same glass envelope) are connected as cathode followers. Their plates are bypassed for r.f. The output signals are taken from the top of the common cathode resistor, R_1 , which is not bypassed. The two triodes are biased to operate on the linear part of their e_c-i_b curves. Since they are twin triodes with the same grid bias (due to the common cathode resistor), they draw equal amounts of plate current.

A cathode follower has this basic property: if a signal is introduced into the tube at the grid, the voltage changes at the cathode will follow those at the grid. As the

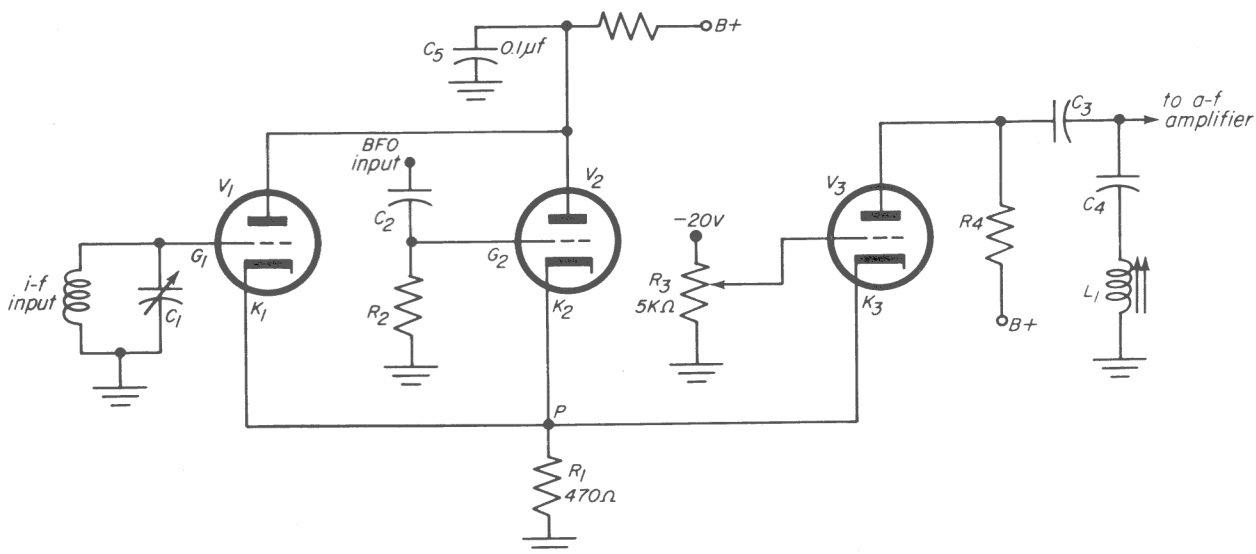


Fig. 35-7

grid is going positive, the cathode will be going positive. This occurs because a more positive grid increases plate current, which, as part of its complete path, flows through the cathode resistor. Increased current flow in the resistor increases the voltage drop across it. Thus the cathode becomes more positive. Similarly, when the grid goes negative, the cathode also goes negative.

But if a signal is introduced into a cathode follower *at the cathode*, the voltage on the grid does not follow the voltage on the cathode. This is so because the grid does not draw current in a normally biased tube. A change in plate current does not alter the control grid voltage with respect to ground.

Let's consider a signal applied to the control grid of V_1 in Fig. 35-7. As the signal goes positive, more plate current flows through V_1 and R_1 . The cathode K_1 will go positive *if nothing prevents* it from doing so. Suppose that the cathode starts to go positive. Since it is connected to the cathode of V_2 , the cathode of V_2 would have to go positive too. This would be the same as if the control grid of V_2 went negative. But when the control grid goes negative with respect to the cathode, less plate current flows through V_2 and through R_1 . With less current from V_2 flowing through R_1 , the voltage drop across R_1 tends to decrease and K_2 tends to go negative. V_2 resists the development of a signal across R_1 .

In short, as more plate current from V_1 flows through R_1 , less plate current from V_2 flows through R_1 . The *total* plate current of the two tubes tends to remain unchanged. With no change in total current at the signal frequency, there will be no varying voltage drop at the signal frequency across R_1 . If an ordinary AM signal is applied to the control grid of V_1 , it produces no output across R_1 . This is the major advantage of the product detector. Unlike the diode detector, it does not respond to amplitude variations applied to its input.

But if V_2 has an external negative bias applied to its control grid (a bias not due to the voltage drop across R_1), it will draw less

plate current. A signal introduced into V_2 at the cathode will not be able to produce as large a plate current change in R_1 as an equal signal applied to the grid of V_1 . Therefore, V_2 will be unable to produce an equal and opposite signal voltage drop across R_1 . Therefore, there will be an output at point P when a signal is applied to the control grid of V_1 .

If, instead of an external bias, a separate signal is coupled to the control grid of V_2 through C_2 , the negative swings of this signal will reduce the plate current of V_2 enough for the signal on the control grid of V_1 to produce an output at point P. Likewise, the negative swings of the signal, applied to the control grid of V_1 will reduce the plate current of V_1 enough to allow the signal applied to the control grid of V_2 to produce an output at P. The signal applied to the control grid of V_1 and the signal applied to the control grid of V_2 will mix in R_1 .

If one signal is a single-sideband signal and the other signal is a BFO signal, the difference frequency is the audio frequency. But the audio content cannot be separated from the complex waveform of the combined signals because R_1 , in which they are mixing, is a linear impedance. The complex waveform is symmetrical and will produce no resultant at the audio frequencies.

But the audio information is separated in V_3 , which is in effect, a plate detector with the complex signal applied to its cathode instead of its grid. V_3 has external negative bias, in addition to that due to the voltage drop across R_1 . This additional bias causes V_3 to operate close to cutoff, on the non-linear part of its e_c - i_b curve. The plate load of V_3 is the resistor R_4 . V_3 detects the signal applied to its cathode, producing an audio resultant in the plate load resistor, R_4 . Any high frequencies (SSB and BFO) appearing across R_4 are shorted by the very low impedance of the series resonant circuit, L_1C_4 , which is tuned to the BFO, or intermediate frequency. At audio frequencies the impedance of L_1C_4 is high because it is not resonant for audio frequencies, and

because C_4 has very little capacitance, and therefore very high reactance, to audio frequencies.

R_3 adjusts the bias on V_3 for optimum performance.

35-5. INTERDEPARTMENTAL COMMUNICATION SYSTEMS

Interdepartmental communication systems are familiarly known as intercom systems. Intercom systems are two way audio communications systems. An intercom system might be used by a busy organization to let the main office keep in instant touch with its various departments, such as stockroom, mailing, repair, personnel, warehouse, etc.

The basic units of an intercom system are:

1. One or more master units.
2. One or more slaves, or remote units or stations.

The master unit contains an amplifier, microphone-speaker, a talk-listen switch, and an array of pushbuttons by means of which the master operator can select the specific remote unit he desires to talk to. The remote unit may be hundreds of feet away, on another floor, or in another building. A cable connects the master unit and

each remote station.

The remote unit contains a microphone-speaker and a talk-listen switch but no amplifier. A remote unit operator can call in to the master unit when the master unit is not already talking to some other remote unit by means of pressing the talk-listen switch to the remote unit to the *talk* position. The switch is spring-loaded so that it will always return to the *listen* position when not held down by the operator.

In both the master units and the remote units, the speaker doubles as a microphone. It is usually a special type of speaker, having a higher-than-usual voice-coil impedance (13 ohms). So that when acting as a microphone, the speaker-microphone will generate the highest possible voltage from the feeble sound pressure on its cone. It has a frequency response suitable to distinct reproduction of speech.

Let's discuss a basic intercom circuit employing one master unit and one remote unit. Figure 35-8a shows the hook-up used when the master unit talks to the remote unit, and Fig. 35-8b shows the hook-up when the remote unit talks to the master unit. At *a*, the speaker associated with the master amplifier, called the local speaker, is being used as a microphone. It is connected to the input of the audio amplifier. A long cable is connected to the output of the audio ampli-

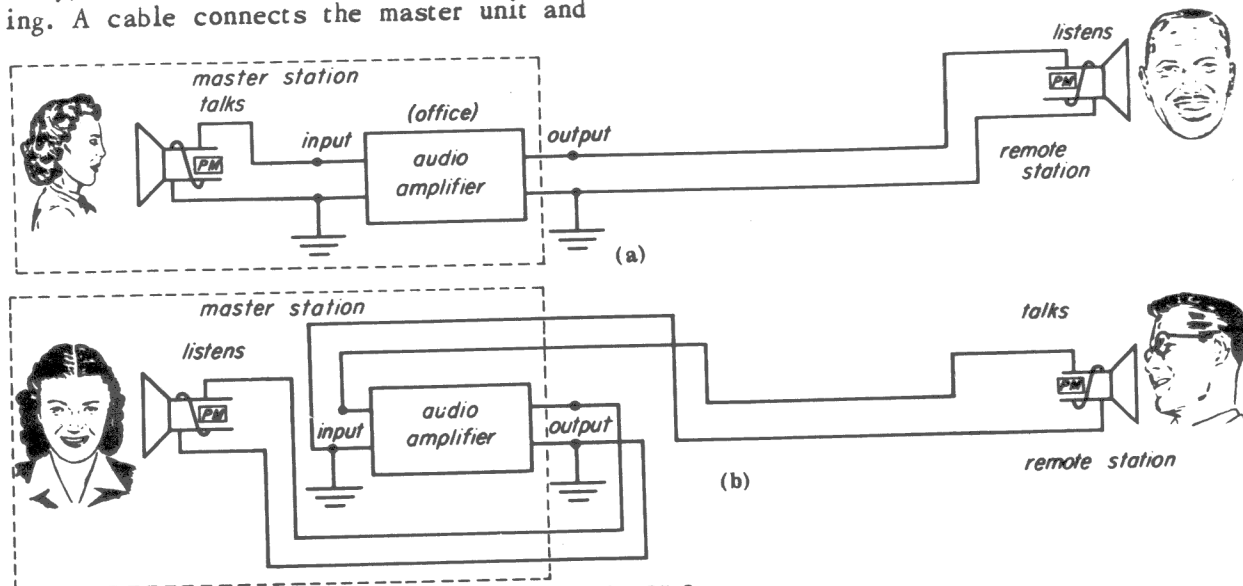


Fig. 35-8

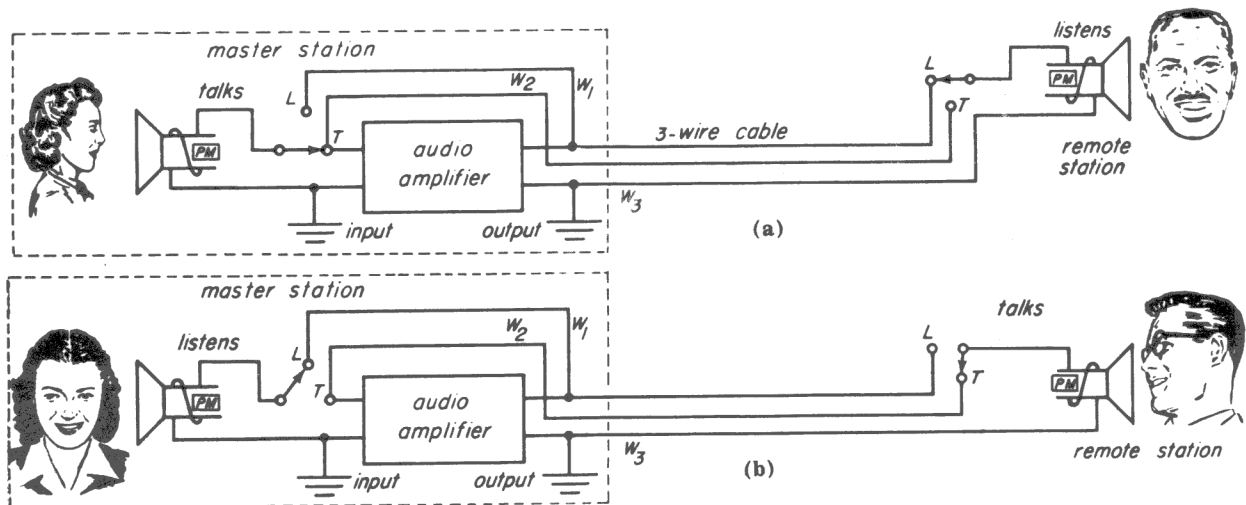


Fig. 35-9

fier. This cable carries the amplified voice signals to the remote unit, where the speaker, acting as a speaker because it is connected to the *output* of the amplifier, reproduces them so that they can be heard throughout the room where the remote unit is. The hook-up shown at *b* is the circuit used when the remote operator talks to the master operator. The local speaker is connected to the amplifier's output and is acting as a speaker; the remote speaker is connected through the long cable to the input of the amplifier and is acting as a microphone while the remote operator speaks into it.

The change-over from basic circuit *a* to basic circuit *b* is accomplished by means of a 3-wire cable and two *talk-listen* switches. One talk-listen switch is on the master amplifier the other is on the remote amplifier. Figure 35-9*a* shows how the switches are used when the master operator calls the remote operator. The master operator depresses her talk-listen switch from the listen (*L*) position (where it is normally held by a spring) to the talk (*T*) position. This connects the local microphone-speaker across the input of the amplifier.

The remote speaker is already connected across the output of the amplifier's output, via wires W_1 and W_3 , by the spring which holds its talk-listen switch in the listen (*L*) position.

When the master operator's voice is heard in the room that contains the remote unit,

the clerk there immediately comes over to the remote unit so that he can operate the talk-listen switch when he is ready to answer the master operator. When the master operator has finished speaking, she releases the master talk-listen switch, which returns to the listen position and connects the local speaker across the output of the amplifier. At the same time, the clerk at the remote unit depresses the remote talk-listen switch to the talk position, thereby connecting the remote microphone-speaker across the input of the amplifier, via wires W_2 and W_3 .

In order to connect more than one remote station, an additional switch is required, so that the master operator can select, by turning the switch (or by pushing a button if a push-button type switch is used) the specific remote station he wishes to talk to. Figure 35-10 shows how the additional switch is usually connected. (A 7-point switch, S_1 , is shown but only three remote stations are shown, to avoid cluttering the diagram. Obviously, as many remotes can be connected as there are points of the switch.) With such a set-up, when the master operator wants to call a remote station, for instance the garage, she would first turn the station-selector switch, S_1 to the position marked *garage* (or push the button marked *garage*). This would connect the output terminal of the amplifier to the W_1 wire of the garage, putting the speaker of the garage across the output of the amplifier. Then the master operator would press her talk-listen

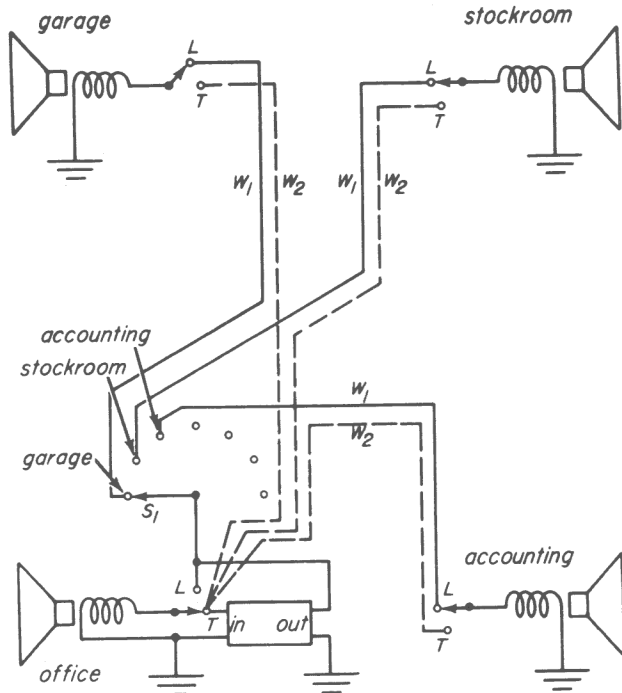


Fig. 35-10

switch to the talk position. The talk-listen switch in the garage would automatically be in the listen position because of its built-in spring. The master operator's voice would be heard in the garage.

In the circuit shown, there is a possible source of difficulty. While the master operator is talking to the garage operator, other operators can call in. When they press their talk buttons, their speaker-microphones are connected across the input to the amplifier. Since the output of the amplifier is connected to the speaker in the garage, the voices of these remote operators, like the voice of the master operator would be heard in the garage. In order to avoid this, another switch—not shown in Fig. 35-10, but shown in Fig. 35-11—is incorporated in the master-unit talk-listen switch. It automatically disconnects all W_2 wires when the master talk-listen switch is in the talk position.

The W_3 ground return wires are shown quite short in Fig. 35-10, as though to indicate that they are grounded at some point close to the speakers. Actually they run all the way back to the amplifier and are grounded at the amplifier. They are shown short to keep the diagram uncluttered. It would not be practical to ground these wires at widely

separated ground points, because in factories, lofts and other commercial houses where heavy machinery is used, such heavy equipment is often grounded. When it is in operation, considerable noise currents may flow through the grounding conductors. If these currents caused even tiny voltages to be introduced into the call-in circuit (W_2 and W_3 wires), the noise voltages would be amplified and would cause objectionable crackling, blasting, or humming.

Figure 35-11 shows the complete schematic diagram of a standard intercom master amplifier. Note the location of the volume control R_6 . It is not located at the input because the input voltages are very small and could not possibly overload the first triode voltage amplifier. There is never any need to attenuate voltages that are so slight. But after the signals are amplified by the first triode, they are much larger and could overload the following triode or the power output tube. Therefore, the volume control is located at the input to the second triode.

Furthermore, this is a three-stage, or high-gain amplifier. Any high impedance device, such as a high-resistance volume control, coupled to the input of a high gain amplifier, may pick up a slight a-c hum signal. This signal, once introduced into the high-gain amplifier, may be heard as a very loud hum in the output. Therefore designers try to avoid the use of high impedance devices at the input to high-gain amplifiers.

35-6. ELECTRONIC TIMERS

An electronic timer is used to open or close a switch after the lapse of a certain time interval. The switch can be used to control lights, motors, heaters, etc.

Timing circuits depend upon the *time-constant* principle you have already learned about. A capacitor discharges through a resistor shunted across it at a rate determined by the RC time constant. The resistor is made variable so that the time constant can be varied. Depending upon the setting of the resistor, the capacitor will discharge to a definite voltage level in a definite time. At the end of this time, the resulting voltage

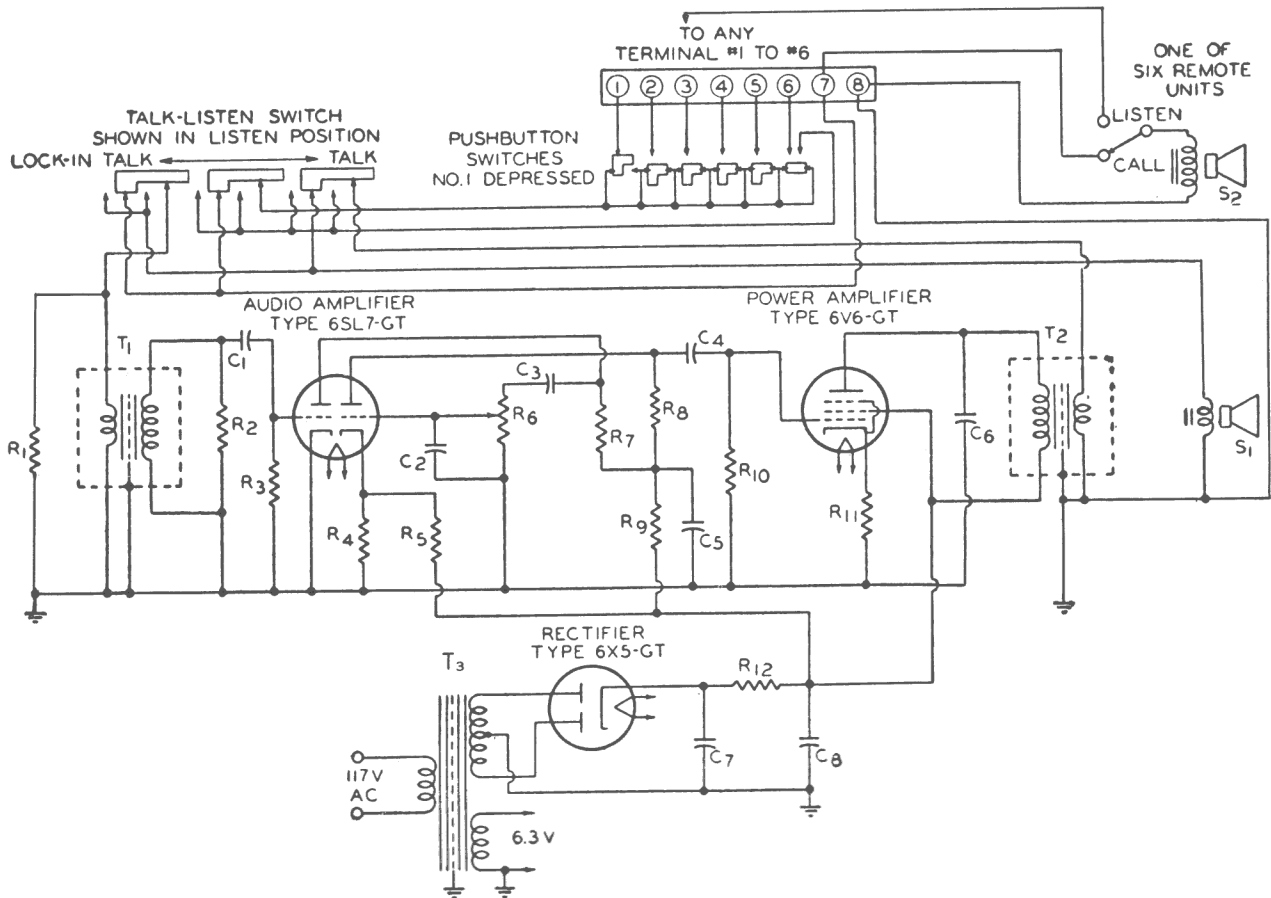


Fig. 35-11

level triggers a biased tube into conduction. A relay in the tube's plate circuit is actuated by the flow of plate current and throws the switch.

The timer mechanism shown in Fig. 35-12 uses the principles just outlined. It is designed for use in a photographer's darkroom. The main function of the timing circuit is to turn on the enlarger's light for a predetermined number of seconds and then turn it off so that the photographic paper is exposed to the enlarger light for the required number of seconds. The line cord of the enlarger light is plugged into an outlet socket on the front panel of the timer. A dim red safelight is plugged into another socket on the front panel.

Figure 35-13 is a schematic diagram of the timing circuit. Function switch S_2 is set to the *normal* position, as shown. (S_2 is spring-loaded in such a way that it will stay in either the normal or the focus positions if it is set to one of these positions. But if

the switch is pressed down to the *print* position, it will come back up to the *normal* position as soon as the finger pressure is removed.) When S_1 is closed, line voltage is applied across the primary of filament transformer T_1 , and across the gas-filled thyratron tube V_1 , via R_5 and the relay winding. There is no initial bias on the grid of V_1 . The filament of V_1 , heated by current from the transformer secondary, brings the cathode up to operating temperature. The tube conducts on the positive half cycles of a.c. As a result, current flowing in one direction passes

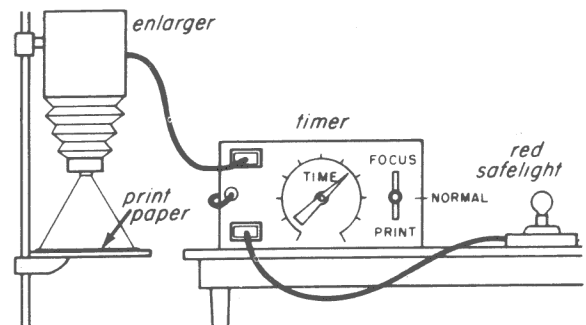


Fig. 35-12

through the relay winding, magnetizing the relay core and causing the armature-switch, $A-S$, to be pulled into contact with point Q . This applies line voltage to socket 2 (safe-light) and to the calibrating potentiometer, R_1 . An alternating voltage, with a level determined by the setting of the slider arm of R_1 is applied via R_2 and C_1 , to the grid of V_1 . On positive half cycles, the grid draws current, developing a charge across C_1 almost equal to the peak a-c voltage and having the polarity shown. This charge biases the grid. During every positive half cycle, this high negative bias is overcome by the slightly higher peaks, causing V_1 to conduct momentarily during each positive half cycle. The periodic conduction causes an intermittent d.c. (rectified a.c.) to flow through the relay winding.

During conduction there is a considerable voltage drop across the relay winding. C_2 charges up to the level of this voltage drop. During the negative or nonconducting cycles, C_2 partially discharges through the relay winding, so that a current flows through the winding in the correct direction even during the nonconducting cycle. Consequently the relay holds the armature firmly on point Q , in spite of a spring trying to pull it over to point P . Without C_2 , the armature would chatter. In the time of one half-cycle, C_2 can discharge only slightly. During the next positive half cycle, it is recharged. It would require the time of several consecutive nonconducting cycles for C_2 to discharge to such a low voltage that relay current would fall enough to let the armature go.

If S_2 is now momentarily moved to the *print* position, as shown in the figure by dashed line, the cathode of V_1 has its return to the power line opened. Relay current is interrupted long enough for the relay to let the armature go. This starts the timed interval. The spring pulls the armature into contact with point P , lighting the lamp in the enlarger, and beginning the exposure of the photographic paper, upon which the image from the illuminated negative is focused. The a.c. is simultaneously removed from point Q , so that no positive half cycles are applied to the tube's grid to cause conduction. The charge on C_1 holds the grid at

cutoff for as long a time as it takes the charge to leak off through R_3 and R_4 , and diminish to a level lower than cutoff, at which time conduction begins again.

With S_2 back in the normal position (returned by the built-in spring), after removal of finger pressure, the cathode return is again closed, so that V_1 is ready to conduct as soon as its grid bias will allow. The time required for the negative bias to fall to conduction level depends upon the amount of the initial charge (determined by the setting of slider S) and the rate at which the charge leaks off (determined by the value of C_1 and the setting of R_4). When R_4 is set to maximum resistance, the charge leaks off slowly, reaching conduction level in about 60 seconds. When R_4 is set to minimum resistance, the charge leaks off rapidly, through R_3 , reaching conduction level in less than 5 seconds.

The calibration control, R_1 , is not set each time a change in the timed interval is required. It is set only once, when the user first acquires the timer. It is set so that the timing intervals established by the setting of the *other* control, R_4 , agree with the scale lettered on the front panel. Once the range of R_4 has been made to match the lettered scale closely, R_1 is not touched again unless line voltage changes considerably, or a component, such as C_1 , changes value due to heat, drying out, etc. Since R_1 is rarely adjusted, its shaft is not brought out through the panel. It remains inside the case. It has a screwdriver slot in its end and is adjusted by a screwdriver tip inserted through a hole in the panel. Such an arrangement prevents its adjustment from being accidentally altered. After it is set, timed intervals are established solely by means of setting R_4 , whose shaft, brought out through the panel, has a long pointer knob on it, to indicate the number of seconds for which R_4 is set.

When R_4 is set to any interval, for example 15 seconds, C_1 will be shunted by just enough resistance to lower its high charge (and the grid's negative bias) to the conduction level in exactly fifteen seconds. Then tube V_1 conducts, the relay operates,

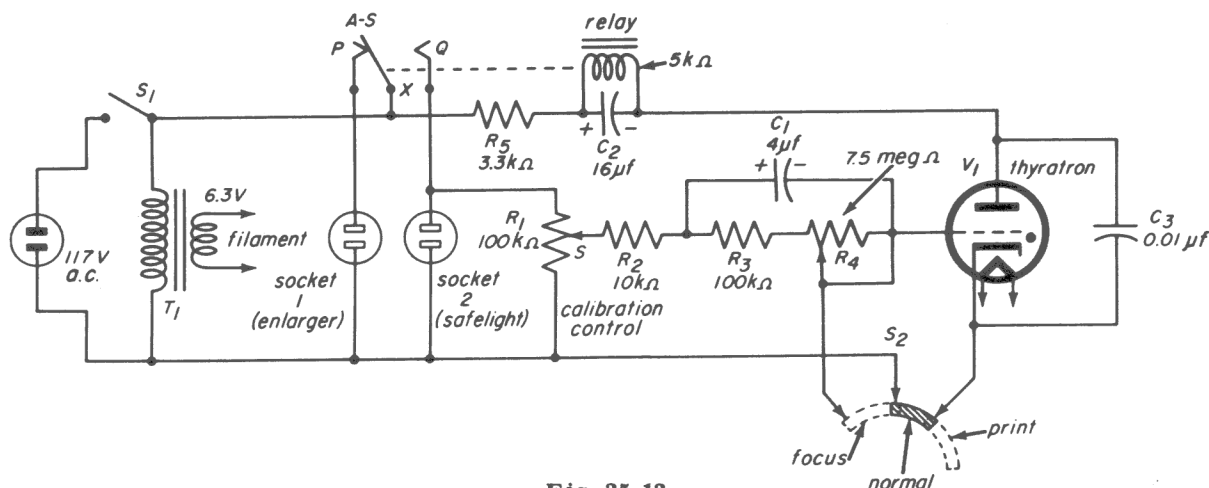


Fig. 35-13

the armature is moved from point *P* (turning off the enlarger light) to point *Q*, turning on the safelight. Thus the print paper is automatically exposed for the correct number of seconds. This automatic monitoring is extremely helpful when many prints of the same degree of contrast are to be made from the one negative.

When it is desired to have the enlarger light on for an untimed interval—as when focusing—the user need only raise the handle of function switch to the *focus* position. In this position, switch *S*₂ breaks the cathode return path of *V*₁, keeping the tube and the relay inoperative. At the same time, *C*₁, if it is already charged, discharges quickly through the switch, *R*₂, and part of *R*₁. With the relay inoperative, the enlarger light is turned on by the spring, which pulls armature *A-S* into contact with point *P*. The enlarger light remains on until *S*₂ is moved from the *focus* position to the *normal* position. In the *normal* position, both the tube and the relay are operative, and *C*₁ is recharged. The safelight is on. The timer is ready to measure the next interval when *S*₂ is momentarily pressed to the *print* position.

The on-off switch, *S*₁, is operated by the same shaft that sets *R*₄. In the extreme counterclockwise position of the shaft, the switch is off.

Thyratrons. Schematically, the tube in Fig. 35-13 resembles the familiar high-vacuum triode, except for the black dot drawn inside the envelope. This dot indi-

cates that the tube has a carefully controlled amount of a specific gas or vapor—hydrogen, argon, or mercury vapor—which was admitted to the envelope after the air was removed.

This tiny amount of gas, under a pressure far lower than atmospheric pressure, causes the tube to conduct with a potential difference of only 15 or 20 volts between cathode and anode (plate) and with zero bias on the grid. At this low potential, the gas ionizes and maximum possible cathode current flows. This heavy starting current occurs because the positive gas ions neutralize the electrons that normally form a space charge around the cathode. With no space charge to hinder them, electrons leave the cathode at its full emission rate and travel in the direction of the plate. If the resistance of the plate load of the tube did not place a limit on the electron flow in the external circuit, the cathode would be quickly ruined. (This is why *R*₅ was included in the timer circuit. It is a current limiting resistor, needed because *C*₂, until it has had time to charge, is practically a short across the relay winding, at the instant first conduction begins: thus, *C*₂ makes the effective resistance of the winding equal to zero.)

When a sufficiently negative bias is placed on the grid, much higher cathode-to-anode potentials can be used without ionizing the gas and starting heavy conduction. But as the bias is lowered and goes below cut-off value, the plate current does not rise gradually as the bias continues to fall – as

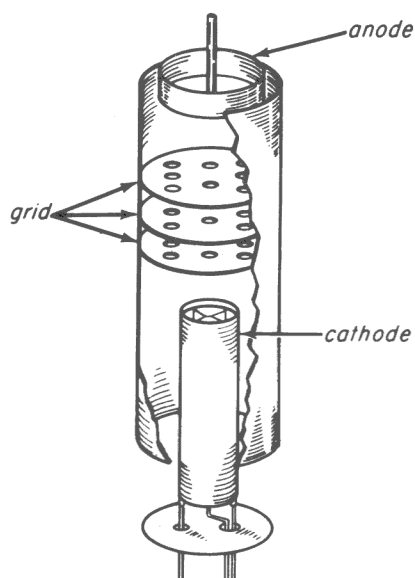


Fig. 35-14

it would in ordinary triodes. In the thyatron, when a certain critical bias is reached, plate current suddenly goes abruptly, not gradually, from a very low value to the maximum that the resistance of the external load will allow. This occurs at the instant of ionization. Once ionization has occurred, making the grid more negative again will not reduce plate current as it would in ordinary triodes. The grid *loses control* when ionization occurs; the negative charge on the grid attracts a small percentage of the ions to itself thereby surrounding its surface with a layer of positive ions which prevents the negative charge from being felt by the remaining ions. (The total of the remaining ions is called the plasma.) Deionization will not occur until the plate voltage falls below the level (15 to 20 volts positive) required to maintain ionization. (In the timer, this happens 60 times per second because a.c. is applied to the plate. If steady d.c. were applied, the gas would not deionize.)

The physical structure of the electrodes in the thyatron, differs from that of ordinary triodes. Figure 35-14 shows an arrangement commonly used. The grid is a metal cylinder, not a wire helix. It encloses the cathode and the plate. This design gives the grid a large surface area which is in contact with the gas. One or more perforated diaphragms in the grid cylinder separates the cathode from the plate; they are almost complete shields between the cathode and the plate. Thus a

small grid bias is able to overcome, near the cathode, the field due to the relatively high voltage on the plate, and prevent the start of ionization until a suitable voltage change occurs at the grid.

The thyatron cannot be considered an amplifier in the usual sense. In a conventional amplifier, the change in plate current is not abrupt but gradual and proportional to the changing grid voltage. Therefore, a thyatron could not reproduce accurately the waveform of a gradually varying voltage on the grid. It is essentially a device with only two useful states – conducting and nonconducting. It is very much like a high speed switch. (A switch may be said to have only two states – conducting and nonconducting.)

In many industrial applications, where high speed switching is of particular importance, thyatrons provide the only satisfactory means of achieving it. But there is a limit to the rate at which even these fast-acting devices can change from the nonconducting to the conducting state, and vice versa. The limit is set by the speed with which the particular gas enclosed in the tube can ionize and deionize. The speed is expressed in microseconds. It varies with the gas pressure, being slower at lower pressures. It is slower for deionization than for ionization. It is considerably slower for thyatrons using mercury vapor than for those using gas. Table A gives typical ionization and deionization times under typical operating conditions, for the two kinds:

In general, mercury vapor types are used where the controlled currents are heavy, as in accurately timed welding.

Tetrode Thyatrons. Tetrode thyatrons are not tetrodes in the same sense that certain high vacuum tubes are tetrodes. The added electrode that makes the thyatron a tetrode is a shield, rather than an added grid. The physical structure of a thyatron tetrode is shown in Fig. 35-15. The control grid is much smaller than in the triode thyatron. The shield has the large surface area and contains the perforated baffles that reduce anode to grid capacitance. The grid is itself partially shielded from the cathode and anode.

TABLE A - THYRATRON IONIZATION AND DEIONIZATION TIME

Type	Ionization Time (μsec)	Deionization Time (μsec)
Gas	0.5	25 to 100
Mercury vapor	10	1,000

The principal advantage of this design is that it minimizes the tendency of the thyatron to draw grid current. In the triode version, as the grid bias approaches the conduction level, a current of several microamperes begins to flow in the grid resistor. In the tetrode design, this current is reduced to about one-thousandth of a microampere. A current as small as this permits the use of a high grid resistor. (The extremely small current cannot develop an appreciable voltage drop across even a 10-megohm grid resistor. Therefore, the grid bias is not appreciably altered by the grid current.) The ability to operate reliably with a high grid resistor is important in circuits where the signal applied to the thyatron grid is obtained from a very high impedance source, such as a phototube. A low grid resistor would load the phototube unduly, reducing its output signal to an unusable level.

35-7. RADIO CONTROL

A human operator can control a remote moving vehicle that is miles away by means of radio. This technique of control by radio requires the following:

1. A transmitter (usually small and portable) by means of which the operator sends commands to the controlled object.
2. A suitable receiver (usually powered by batteries) in the moving object. The receiver picks up the transmitted commands and feeds them to a decoder.
3. A decoder, which is a device capable of responding to the commands and performing the operations that the commands call for. The decoder operates the mechanical controls of the moving vehicle.

The commands are not words spoken by the operator. Instead they are expressed in a code, consisting of pulses, or of audio tones, to which a simple mechanism can respond. Thus, two pulses in rapid succession, might mean *turn right*; three pulses might mean *turn left*, and so on. The decoder can be designed so that two pulses will cause it to move the steering apparatus appropriately for a right turn, three pulses cause it to move the apparatus appropriately for a left turn, and so on. The transmitter is off the air when no pulse is being transmitted, the pulse in this case being simply a short burst of r-f energy.

If audio tones are used for the code, the transmitter will usually be on the air continuously during the control period. For such a code, an audio tone of 150 cps could be used to mean *turn right*, and audio tone of 200 cps could be used to mean *turn left*, and so on.

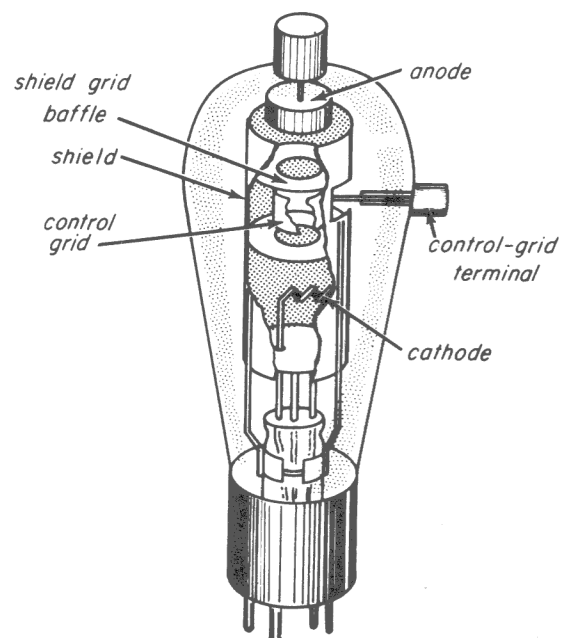


Fig. 35-15

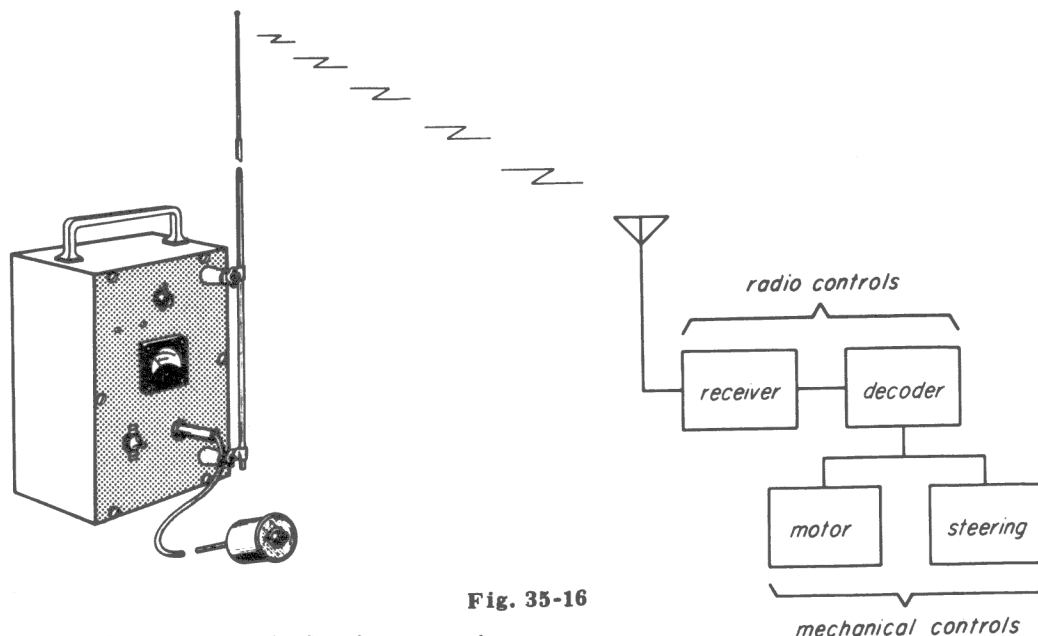


Fig. 35-16

Figure 35-16 shows a block diagram of the general arrangement employed. Where the control operation is a very simple one, such as the opening or closing of a switch, the decoder may be nothing more than a simple relay in the plate circuit of the output stage of the receiver. No loudspeaker is connected to the output stage. Where the control operations are more complex, the decoder is comprised of a rotating device (called an escapement) together with the plate-circuit relay. The pulses applied to the relay are converted into rotary motion, which may easily be translated into reciprocating (side-to-side, or back-and-forth) motion to operate a mechanical control.

Small model airplanes, driven by tiny gasoline engines, are often radio-controlled and are steered by a decoder of the simple type shown in Fig. 35-17. This arrangement may also be applied to radio-controlled boats. It is a means of setting the rudder to a right-turn position, to a straight-ahead (or neutral) position, or to a left-turn position. Only the essential parts of the mechanism are shown. The supporting framework is omitted for the sake of clarity. The escapement consists of a rocker-type armature on the relay, and a rotating bar (ends marked *M* and *N*) attached firmly to a thin stiff wire bent like a crankshaft and having a hook at one end. A long rubber band is looped into the hook and then wound with many turns and attached to another hook, which is at the rear of the

usage. The rubber band keeps the wire crankshaft under constant rotary torsion so that the escapement bar is constantly trying to turn in the direction shown by the curved arrow. But, as shown at *b*, the tips of the bar, *M* or *N*, catch on the rocker and cannot move unless the rocker moves out of the way. The rocker has two positions — one of them (solid outline) when the relay pull is stronger than the spring pull, and the other (dashed outline) when the relay pull is weaker than the spring pull. As pulses (bursts of r-f energy from the transmitter) are picked up by the receiver, the plate current of the output tube is varied. This varying plate current, maximum when no burst is coming in and minimum when a burst is coming in, makes the relay pull stronger or weaker than the spring pull. Each time the rocker moves from one position to the other, the end *M* or *N* escapes the rocker and the bar makes a quarter-turn. If no pulse comes in, the rocker remains steadily in the position shown by the solid outline; if a continuous r-f signal comes in, the rocker remains in the position of the dashed outline until the r-f signal ends. Thus the operator on the ground can move the rocker to either position, and hold it at either position, at will.

Now let us turn our attention to Fig. 35-17a and to the wire crankshaft and the

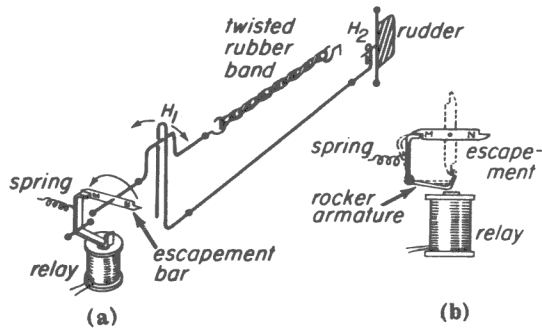


Fig. 35-17

long hairpin loop, H_1 through which it passes. (The black dots on the wires indicate points where the wires are pivoted in the framework.) As the crankshaft turns with the escapement bar, the hairpin loop is swung from side to side by the rectangular offset of the crankshaft. This also swings the small hairpin loop, H_2 , from side to side. A stiff pin on the rudder passes through H_2 and moves from side to side with it. Thus pulses sent from the ground transmitter move the rudder. The ground operator can move the rudder to a left-turn position, or to a right-turn position and hold it there as long as he pleases. Or he can move it to a neutral position for as long as he pleases. He can keep the plane under his control until its small supply of gasoline is used up and it coasts to a landing. The operator knows by his watch when its gasoline is about spent, and brings it in close before the motor stops.

Several more complicated versions of the escapement just described are in use, but they do not differ in principle and therefore are not discussed here. Let us, however, consider a decoder operating on a different principle — tuned reeds.

It is possible to arrange relays so that they will be actuated only when a specific audio tone, modulated upon the transmitted carrier, is received. When this system is used, the relays stop or start tiny motors. The motors operate the mechanical controls. The system is shown in Fig. 35-18, pictorially at *a* and schematically at *b*, and represents a three-relay system. In this circuit, the relays are not energized by the plate current of the output tube, but by a small separate battery, *B*. The plate current is used to energize an electromagnet, L_1 , with a broad poleface close to which three

tuned reeds (TR_1 , TR_2 , and TR_3) are located side by side. Below each reed, but not touching it, is a contact point on a brass strip. The reeds are made of suitable magnetic material. (Note that the brass strips are not magnetic.) Each reed has a suitable length or thickness to make its natural period of vibration different from the other two. Thus TR_1 may vibrate at 100 cps, TR_2 at 175 cps, and TR_3 at 250 cps.

The steady plate current of the tube is not sufficient to pull the magnetic reeds downward into contact with the pole-face; the spacing between pole-face and reeds is deliberately made large to avoid this. When a received audio tone varies the plate current at 100 cps, TR_1 responds, and vibrates vigorously at its natural resonant frequency. The other tuned reeds do not respond. The amplitude of the swings of TR_1 at its natural resonant frequency are great enough to bring it into contact with its contact strip with every swing. Thus the circuit of relay 1 is closed 100 times per second. Resistor R_1 and capacitor C_1 act as a filter to the unidirectional current pulses that result, blending them into a fairly steady d.c., which closes relay 1. Relay 1, when closed, turns on motor 1.

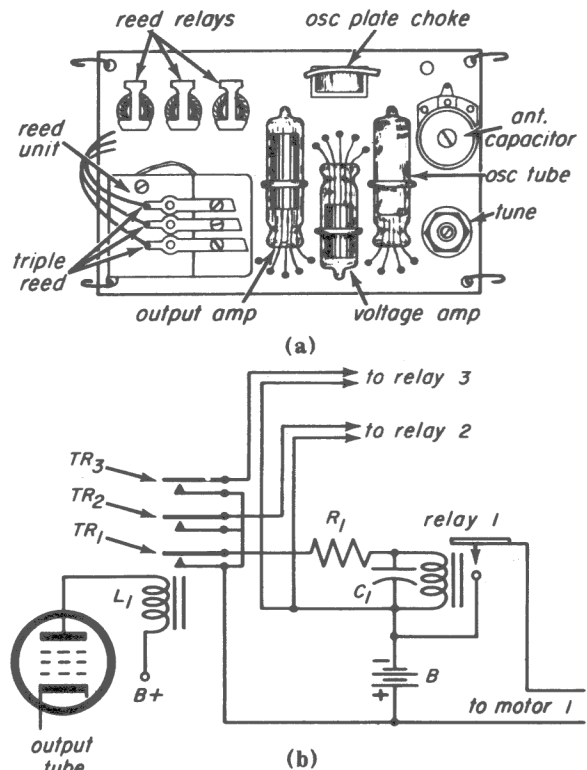


Fig. 35-18

In a similar manner, when a 175 cps tone is received, TR_2 vibrates, actuating relay 2 which turns on motor 2. A 250-cps tone actuates relay 3 and thus turns on motor 3.

The motors could not be turned on directly by the tuned reeds, without relays 1, 2, or 3. The motors have relatively low resistance windings which — if connected across C_1 like the relay winding — would hold the charge at a very low level. Most of the battery voltage would be wasted in the voltage drop across filter resistor R_1 . The motors would not start.

If this type of control device is used for controlling the operation of a remote vehicle, and only two motors are required for motion (for example, to give forward or reverse motion in a boat), the third relay could be used to turn on the lights, or to operate a steering escapement.

Receivers for Radio Control. In military work, or in large professional demonstration models, receivers and receiver-operated control circuits may be quite complicated. Several receivers may be used in one vehicle, and many control operations performed. Such receivers and controls constitute a special study. But you can gain an understanding of the principles of radio control by studying the small receivers used by hobbyists, which embody the main principles of radio control, and are relatively simple.

For the reception of audio-tone-modulated signals in a tuned-reed system, a super-

regenerative detector, followed by two stages of audio amplification is generally used. Subminiature tubes are employed because they occupy little space and have little weight. Miniature batteries supply the power. A typical circuit is shown in Fig. 35-19. The receiver is designed to operate at 27.255 mc the *Citizen's frequency* allotted by the FCC. Two stages of audio amplification are used to ensure that a vigorous audio current will flow in the winding of the electromagnet, L_2 , providing reliable operation of the reeds.

The cored inductor, CH , is not a filter choke, but an audio reactor serving as the portion of the plate load of V_1 across which the audio signal develops. In order to super-regenerate, V_1 requires more plate current than V_2 or V_3 ; at the current drawn, a resistor in place of inductor CH would allow too large a drop of d-c voltage. The impedance of the inductor allows a large audio voltage drop, but its low d-c resistance prevents a large d-c voltage drop. Thus the plate supply voltage of V_1 remains at a usable level. R_4 and C_5 constitute a decoupling filter. They prevent audio feedback between the electromagnet and CH .

The antenna of the receiver is very short. It is coupled directly to the grid end of the combination tuning-and-oscillator coil, L_1 , for maximum transfer of its small signal to the input control grid. L_1 is adjustable over a very narrow range, by means of its movable powdered iron core. This allows L_1 to be accurately tuned to 27.255 mc.

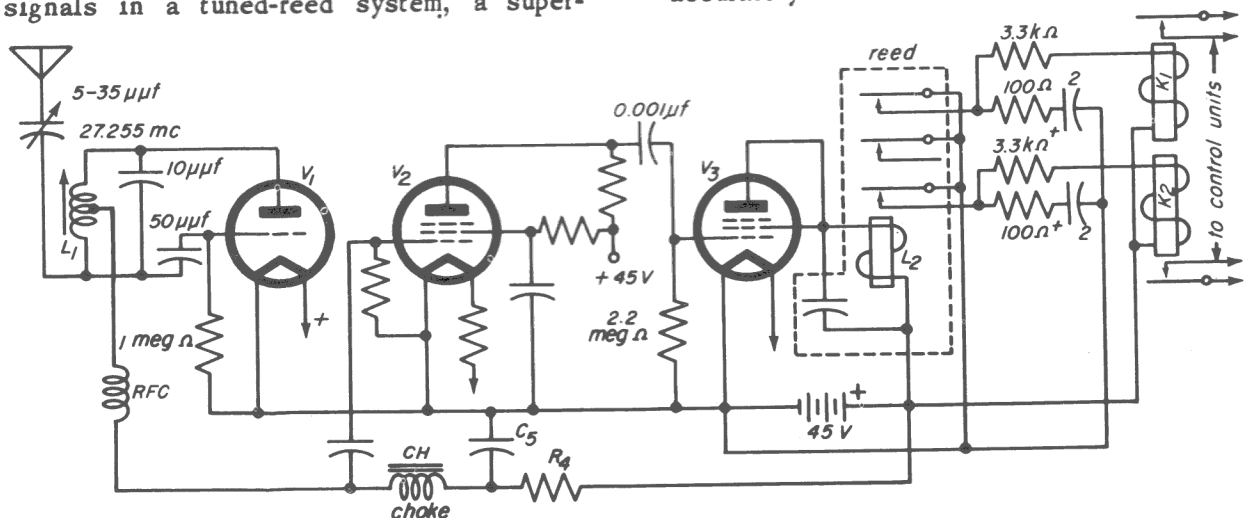


Fig. 35-19

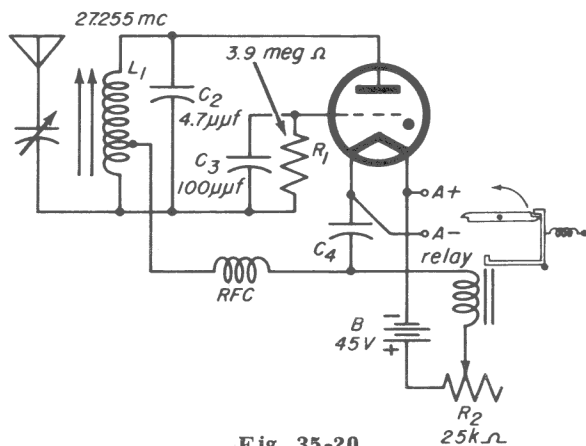


Fig. 35-20

The receiver radiates appreciably. This fact is put to use. If the motor of the model plane fails while the plane is far from the operator, the plane cannot be brought back. But the location of the plane may be traced by the radiation of its superregenerative receiver. A special portable receiver, directional and highly sensitive, can pick up the radiation and show its direction, thus leading the operator to the lost plane.

In the control of light-weight model planes, where the escapement method of decoding is used, a single tube superregenerative receiver is usually adequate (Fig. 35-20). A very sensitive relay in the plate circuit of the tube operates with a current change in its winding of approximately 1 ma. The receiver generally uses a miniature thyatron, specially made for such service. The circuit can be adjusted so that it is just on the verge of oscillation, but not quite able to achieve it. When a signal, even a faint one, comes in, the additional energy in the tank circuit tips the balance and oscillation begins. Oscillation builds up a negative bias on the grid, causing the average plate current to drop sharply, from approximately 1.3 ma to approximately 0.2 ma. Since the relay responds to the average plate current, but not to the individual r-f cycles, it is actuated by the 1.1-ma change of current in its winding, and the armature springs away from the magnet, releasing one end of the escapement bar. At the end of the signal, plate current returns to 1.3 ma, the relay closes, and the bar escapes again.

The special thyatron is used in preference to a standard tube because, in the

thyatron, a given change in grid bias can produce a larger change in plate current. This makes the operation of the relay more certain. It might seem that B+ voltage is applied to the control grid in the schematic diagram of Fig. 35-20 (through R_2 , the relay winding, the radio frequency choke, tank coil L_1 , and grid leak resistor R_1). But a positive voltage on the grid causes grid current to flow through R_1 , producing a large voltage drop across the high value resistor. Consequently B+ voltage applied to one end of the resistor is automatically lowered to a very small value at the grid end. A slight grid current is not abnormal in the operation of triode thyatrons.

Radio-Control Transmitters. A wide variety of transmitters are used in radio control. In order to operate a transmitter legally, even on the Citizen's frequency, 27.255 mc, the operator must have a license. The license for operation on the Citizen's frequency is free and no examination is required to obtain it, but you must fill out the appropriate application form (Form 505) and mail it to your nearest FCC office. An applicant must be over 18.

The transmitter must be crystal-controlled and may have an input power no greater than 5 watts. The circuit of a low powered transmitter, suitable for steering a model airplane or boat, is given in Fig. 35-21. When keyed, it oscillates, generating r-f energy in the manner of the familiar Hartley oscillator. In order that the generated energy may be applied to an antenna, the plate load is a tuned tank circuit, L_2C_1 , coupled to L_3 , which is in series with the low end of a vertical quarter-wave whip antenna. The low end of L_3 is grounded to the metal case. The metal case must make contact with the ground by resting on the ground, because the vertical quarter-wave antenna utilizes the ground as another quarter-wave section, in order to achieve the effect of a vertical half-wave antenna, and get the utmost efficiency of radiation.

Keying the transmitter—that is, making it oscillate and radiate—is accomplished by closing the circuit between the B+ terminal and the screen grid of the tube, which will

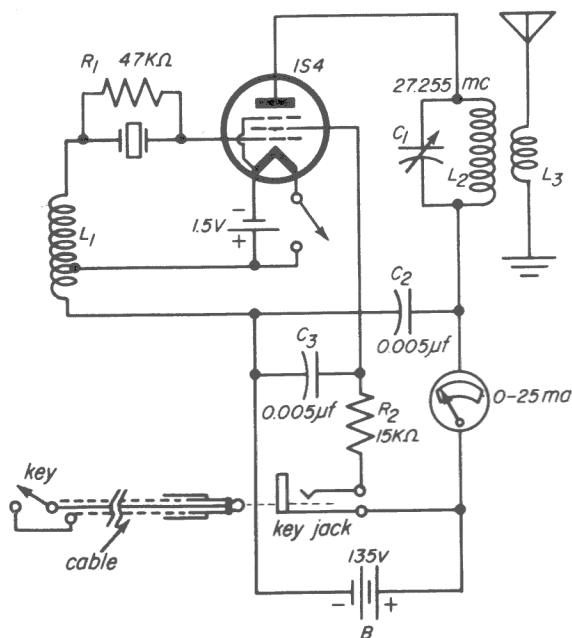


Fig. 35-21

not oscillate when there is no screen grid voltage. The circuit is closed by an external key or switch on the end of a three-to-four foot long two-lead cable. The other end of the cable, equipped with a suitable plug, is inserted in the key jack. When the external switch is closed, the B+ terminal

of the battery is connected through the cable and R_2 to the screen grid.

The meter in the plate circuit of the tube is needed as a guide when the coupling between L_2 and L_3 is adjusted and when C_1 is set to tune the output tank to the correct resonant frequency. When these adjustments are correct and the transmitter is resting on a good ground (not concrete or dusty soil), the meter should read 12 ma when the key is held closed.

Oscillator coil L_1 consists of 30 turns of No. 22 d.c.c. (double cotton covered) wire, wound closely on a bakelite rod of 1/4-inch diameter; tapped 3 turns from lower end. L_2 consists of 11 turns of No. 14 insulated wire (not necessarily double cotton covered) on a form of 1-1/8 inches long and 3/4-inch in diameter. L_3 consists of 5 turns of the same wire on a 3/4-inch diameter. If the wire used for L_2 and L_3 is stiff enough to be self-supporting, the forms may be slipped out and discarded. But make sure that the coils keep their dimensions after removal.